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STUDY OF SOLID ROCKET MOTORS FOR A SPACE SHUTTLE BOOSTER

FINAL REPORT

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APPENDIX D RECOVERY AND REUSE 156-IN.-DIAMETER SOLID ROCKET MOTOR BOOSTERS



United Technology Center

DIVISION OF UNITED AIRCRAFT CORPORATION

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**STUDY OF
SOLID ROCKET MOTORS
FOR A SPACE SHUTTLE BOOSTER
FINAL REPORT**

**APPENDIX D
RECOVERY AND REUSE
156-IN.-DIAMETER
SOLID ROCKET MOTOR BOOSTERS
15 March 1972**

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**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, ALABAMA**

by

United Technology Center

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PREFACE

The results of previous studies on the recovery of SRMs have indicated that the most expensive elements of the SRM hardware (i.e., case segments, forward and aft closures, attach structures, and nozzle steel) are recoverable with an attrition rate of less than 20%, and that these high recovery rates are primarily due to four factors:

- A. Utilization of a proven parachute recovery technique
- B. Low impact loads resulting from SRM entry into water at velocities under 90 ft/sec
- C. Inherent strength and stiffness of the SRM, which is designed not only for external flight loads but also for high internal pressures on the order of 900 to 1,000 psi
- D. Segmentation and interchangeability of all SRM hardware components.

Recovery system operations are described briefly in the following paragraphs.

The launch vehicle rises through the atmosphere and accelerates until SRM burnout. After booster burnout, the SRM separates from the orbiter and begins tumbling at decreasing rates until free of the atmosphere. The energy at burnout sustains the SRM in ballistic flight to an apogee at 39 nm. During this period "in vacuo," the tumbling rate is constant at about 10 rpm. As the SRM enters the sensible portion of the atmosphere, the nozzle end tends to lead the forebody, and the SRM nutates. At this point, temperatures have peaked to 400° to 500°F by aeroheating. At 32,000 ft, the ribbon drogue is deployed, and 46 sec later the vehicle is positioned vertically, nozzle down, with four 120-ft-diameter canopies mushrooming 200 ft overhead. Eight thousand feet below and several miles away, recovery ships maneuver toward the impact points.

The heat shield crushes under water impact loads at an entry speed of 53 mph (77 ft/sec). Within 5 ft of water entry, the major impact forces are dissipated. The slap-down effect, as the SRM nose drops, is absorbed by the high strength and stiffness of the steel case; however, the relatively thin aluminum nose cone could be damaged by secondary impact in high seas. The SRM experiences the normal inertia and buoyancy forces during the remainder of the penetration. A maximum immersion of 65 ft results after impact. The motion of the SRM is thus highly damped, and the SRM shortly comes to rest intact on the sea with the nozzle immersed slightly below the waterline and with a large volume of air entrapped within the steel motor case to ensure flotation.

Location aids enable the recovery ships to engage the floating SRMs. Pyrotechnic and explosive circuits are disconnected from the SRMs, and inflatable rubber rings are then installed fore and aft to provide flotation stability and protection from damage as the SRMs are floated into an LSD. Four SRMs are retrieved within 6 hr after touchdown, and the components are off-loaded at the ETR naval docks 26 hr after impact. Each item is then cleaned and evaluated for refurbishment, reprocessing, and reuse.

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ABBREVIATIONS

ETR	Eastern Test Range
ISDS	inadvertent separation detection system
LSD	landing ship dock
MEOP	maximum expected operating pressure
MPI	magnetic particle inspection
MRB	material review board
NDT	nondestructive testing
SMAB	solid motor assembly building
SRM	solid rocket motor
TVC	thrust vector control
UTC	United Technology Center

1.0 INTRODUCTION AND SUMMARY

1.1 INTRODUCTION

This study provides the baseline for a space shuttle configuration utilizing two parallel-burn, 156-in.-diameter SRMs with three segments and TECHROLL® seal movable nozzles. The concept and general economic benefits of SRM recovery presented herein are equally valid for the series-burn SRMs, provided that those SRMs are also designed for the same strength, stiffness, segmentation, and interchangeability as the present design, and that those SRMs are also recovered as individual units.

In late 1963 and again in 1965, feasibility studies were initiated by DTC to investigate SRM recoverability. These studies were based upon recovery of the SRM boosters for the Titan III-C. Ground rules established at the outset of the study precluded SRM modification that required significant changes in motor qualification or schedule under the Air Force 624A Program. Even with this restriction, the study determined that the recoverable booster concept was completely feasible, both technically and economically.

The present study has not only substantiated the gross results of the 1963 and 1965 studies but has confirmed the favorable economics of the parachute recovery system. Parachute recovery has been selected as the best method, principally because it can accomplish the task with a minimum development cost and time to achieve operational recovery status. This system affords the highest probability for achieving the large cost reductions presented in section 2.0.

The study accomplished the following objectives: (1) formalized booster recovery requirements; (2) described technical properties of the applicable recovery system; and (3) examined SRM design compatibility considerations including separation, atmosphere reentry, stabilization, terminal deceleration, water impact, immersion, flotation, retrieval, refurbishment, and reuse.

Although the basic purpose of recovering space boosters is to reduce the overall cost of a space booster system, certain other benefits may accrue.

One is the upgrading in reliability afforded by first-hand evaluation of flight hardware upon recovery. Another is a demonstration of the feasibility of reusing booster vehicles. UTC feels that this will become an economic necessity in the near future. With a recoverable system, the direct operating costs can be reduced significantly.

1.2 RESULTS AND CONCLUSIONS

Specific results and conclusions reached in the course of the study are:

- A. From the standpoint of minimum cost and development, parachutes are the best means of achieving SRM recovery.
- B. A cost saving of approximately \$750 million for mission model No. 1 (445 shuttle flights) can be realized by recovering major components of the SRM.
- C. The 156-in.-diameter SRM inert weight of 158,000 lb results in an impact velocity of 77 ft/sec with four 120-ft parachutes.
- D. Major SRM components can be reused safely. The margin of safety is sufficient after seven reuses to ensure man ratings.
- E. Hydrotests are required to qualify motor cases for reuse.
- F. From the standpoint of hydrostatic loading, nozzle-first vertical water entry is more favorable than nose-first entry.
- G. More than 65% of the inert initial dollar value can be expected to be recovered from nozzle-first water impact at 77 ft/sec.
- H. The SRM tumbles after separation at a fairly slow rate, and after reentry stabilizes to the nozzle-first attitude with slow decaying roll and nutation about the center of gravity.
- I. The weight added to provide a parachute recovery system is 7,500 lb per SRM; the effect of booster recovery system weight on the shuttle payload is, therefore, slight.
- J. Aerodynamic heating will not be excessive during reentry; it is not expected to exceed 550°F on critical areas. (Since the cases are tempered at 1,200°F, no degradation will occur at temperatures below 1,000°F.)

- K. Temperature of the nozzle throat insulation will be 2,500°F at water impact; the insulation will be completely destroyed by immersion.
- L. Broadside entry results in damage to the SRM. However, vertical nozzle-first impact at 77 ft/sec will not cause structural damage to the major components. Buckling depths are not exceeded. Nozzle-first entry results in loss of the nozzle extension cone. The slap-down effect as the SRM nose drops is absorbed by the high strength and stiffness of the steel case; however, the relatively thin aluminum nose cone could be damaged by secondary impact in high seas.
- M. No design changes are required in the SRM to affect recoverability except for incorporation of the parachute system in the nose cone and possibly the addition of one hydraulic shock absorber to supplement the existing TVC hydraulic actuators, which in themselves are excellent shock absorbers. The aft portion of the nozzle exit cone is also an excellent design since it is fabricated of wrapped silica-phenolic cloth which will fail incrementally, thus absorbing and dampening the impact loads.
- N. The SRM will float unaided with the nozzle immersed at a pitch attitude of 5 to 10 degrees. Survivability is excellent.
- O. SRMs will be in the water less than 20 hr before reaching ETR by LSD. The LSD can easily load four SRMs, wash them down with fresh water, and return to the ETR naval docks for off-loading within 10 hr.
- P. Salt water and galvanic action will not pose recovery problems to the major recoverable components providing a rinse and dry procedure is initiated after water removal. Experience with refurbishment of hardware for the five-segment 120-in.-diameter SRM from the Titan III Program indicates that water effects, corrosion, and hydrogen embrittlement experienced over a 4-year period did not affect refurbishment and successful test of such hardware on the seven-segment 120-in.-diameter SRM qualification program. To preclude salt water penetration into crevices of the nose section and aft skirt components, a rubberized spray coating will be used after component assembly.

Q. The worst-case impact analysis shows a maximum of 8.8-g impact load for SRM splashdown at 77 ft/sec. (The motor itself is designed for a sustained axial load of 10 g under fully loaded conditions and is, therefore, capable of withstanding short-term axial decelerations greater than 16.5 g. On this basis alone, SRM water impact velocities in excess of 90 ft/sec can be tolerated.) However, an additional factor of safety is achieved by using the aft end hydraulic nozzle actuators as shock absorbers. The load mitigation from these hydraulic shock absorbers is not included in the analysis, but will significantly reduce the impact of gravitational acceleration on the SRM.

1.3 RECOMMENDATIONS

It is recommended that a recovery system development program be initiated. Full-scale demonstrations should include:

- A. Water impact test of the motor at 77 ft/sec to verify SRM component survivability using existing motor hardware
- B. SRM water flotation tests to verify and evaluate the flotation attitude, stability, leakage characteristics, pickup requirements, and effects of surface wave action
- C. Tests to verify that shock loads resulting from entry into the water at 77 ft/sec do not ignite the safe and arm pyrotechnics for the destruct and thrust termination system
- D. Tests to evaluate the effect of salt water, salt-water spray, and corrosion on SRM components
- E. Evaluation of protective coatings for SRM hardware
- F. Air-drop tests of the parachute recovery system using dummy payloads (or 1200-series motors)
- G. Multiple hydrotesting of three segments and two closures to establish multiple reuse reliability using existing seven-segment test hardware

- II. Nozzle impact load testing to verify action of the shock absorbers and failure mode of the extension cone
- I. Evaluation of LSD recovery operations at sea
- J. Model testing, analytical studies, and specimen tests to help define the recovery and refurbishment requirements.

1.4 DISCUSSION

The following paragraphs discuss the proposed plan for recovery, ret. eval, and reuse of the SRMs.

1.4.1 Parachute System Sequence

The parachute system consists of the following components which are similar to those qualified from previous programs:

<u>Component</u>	<u>Program</u>
Pilot chute extraction system	Gemini
Pilot chute	Project Asset
Mortar	Gemini and Mercury
Drogue chute	Project Asset
Main parachutes (modified)	Classified Air Force Program
Sequence controller	Apollo

The sequence controller is activated at SRM burnout by the same signal which activates SRM separation (see figure 1-1). At an altitude of 32,000 ft, the nose cone is separated and, following a 2-sec delay, the pilot chute is deployed by mortar ejection. The pilot chute extracts the 44-ft-diameter drogue chute, which is fully disreefed at an altitude of approximately 19,500 ft.

At an altitude of 10,000 ft, the sequence controller initiates drogue release (see figure 1-2). The drogue assembly then extracts the four 120-ft main parachutes. At 8,000 ft, the main chutes are disreefed, providing a terminal descent velocity of approximately 77 ft/sec.

Two seconds after water impact, the main chutes are separated from the booster on the command of an impact switch signal, which also activates flashing lights.

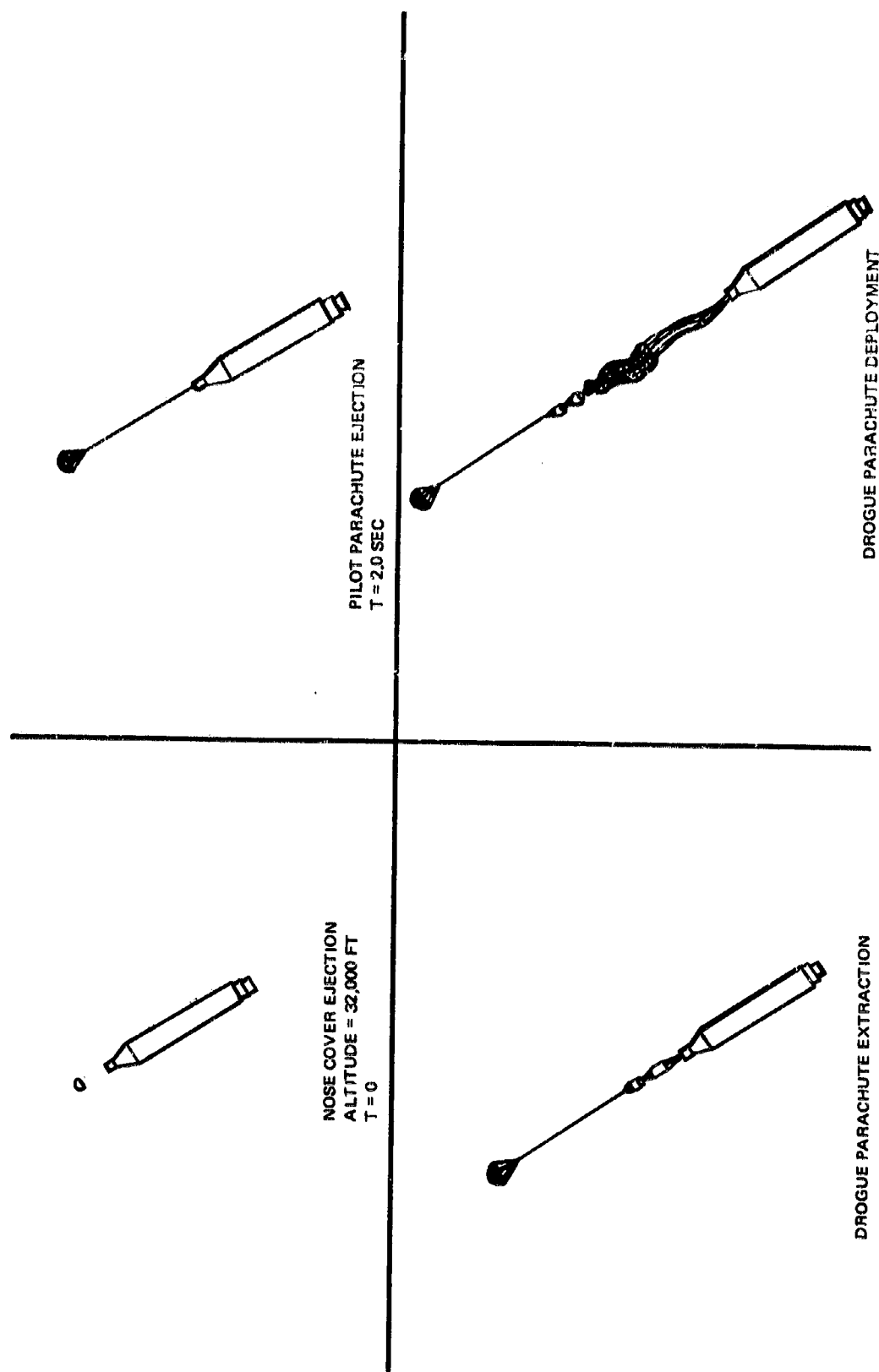


Figure 1-1. Parachute System Sequence

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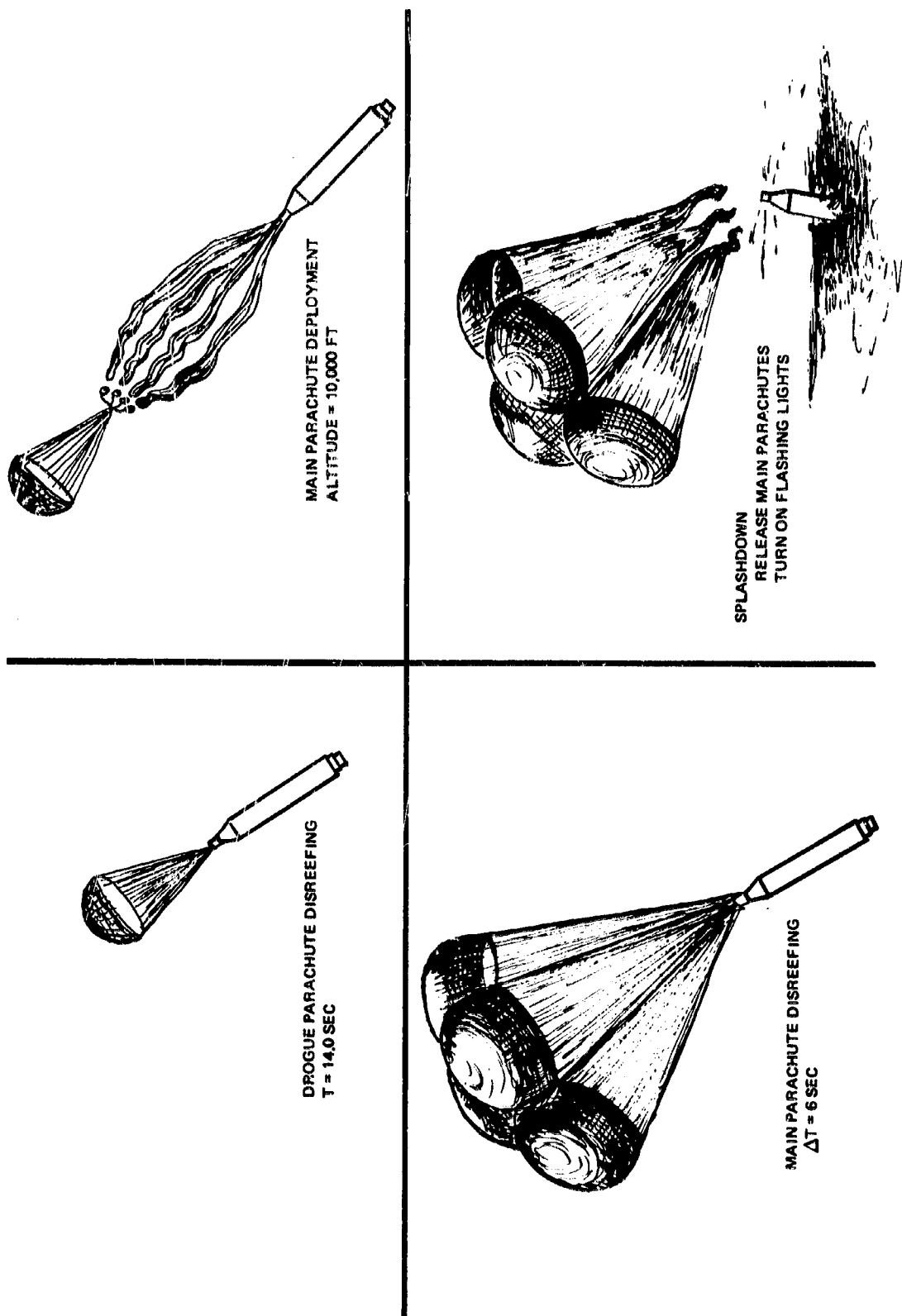


Figure 1-2. Parachute System Sequence

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1.4.2 Parachute Sequence Controller

The sequence controller subsystem, which consists of an electric sequencer, transducers, and an electrical harness, provides the necessary sequence of events during deployment and recovery cycles. Design studies have indicated that the basic Apollo command module sequencer can be used, but with the abort sequence eliminated. This sequencer contains two parallel systems and has a reliability factor in excess of .9994.

Auxiliary components used in the sequence controller subsystem include altitude and impact sensing switches and necessary harnessing and cabling. These components have already been flight qualified and are available for use.

A functional block diagram of the sequence controller subsystem is shown in figure 1-3. As indicated, the sequence controller will control all parachute and recovery aid events during the recovery cycle. The recovery cycle will be initiated after SRM burnout and separation by enabling the sequence controller with a positive separation signal from the booster.

1.4.3 Recovery System Development Profile

In designing the parachute system, it is important to minimize the pressure loads on the parachutes and the gravitational acceleration impact loads on the SRM. For this reason a pilot chute and drogue chute precedes the main chute system, and reefing of the chutes is used to control loads. As shown in figure 1-4, the dynamic pressure and velocity is reduced incrementally so that main parachute deployment will occur below 250 psf dynamic pressure and 500 ft/sec.

The maximum skin temperature from aerodynamic heating as the SRM free falls is 550°F. Strength and reliability of the D6aC steel case is not affected until the temperature exceeds 1,000°F (the steel case is tempered at 1,200°F).

1.4.4 SRM Attitude During Flotation

The SRM enters the water at approximately 77 ft/sec, and the impact load of approximately 4.5 g is absorbed by incremental loading on the nozzle, and by compression of air in the chamber as water rushes into the SRM. The

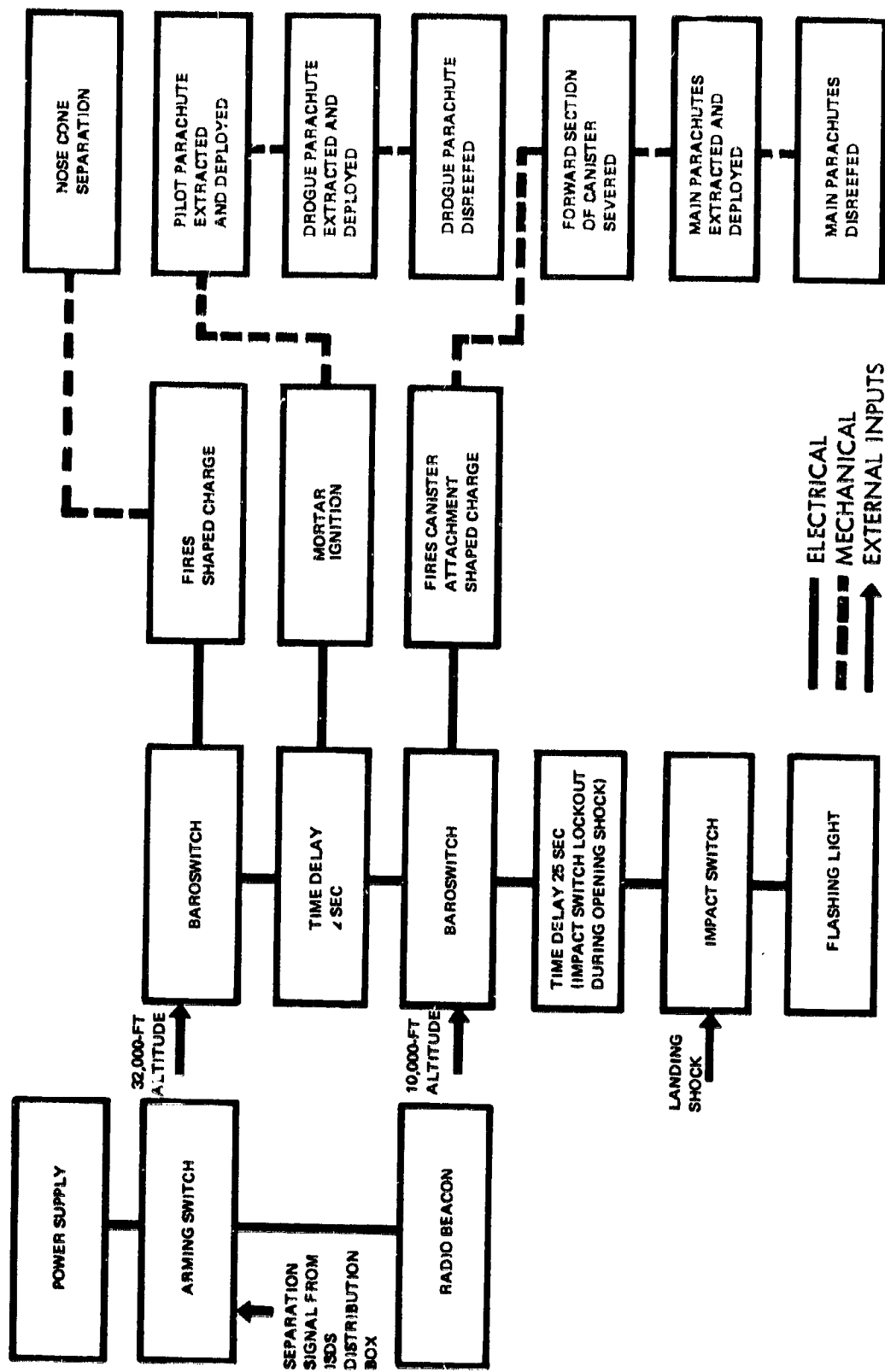
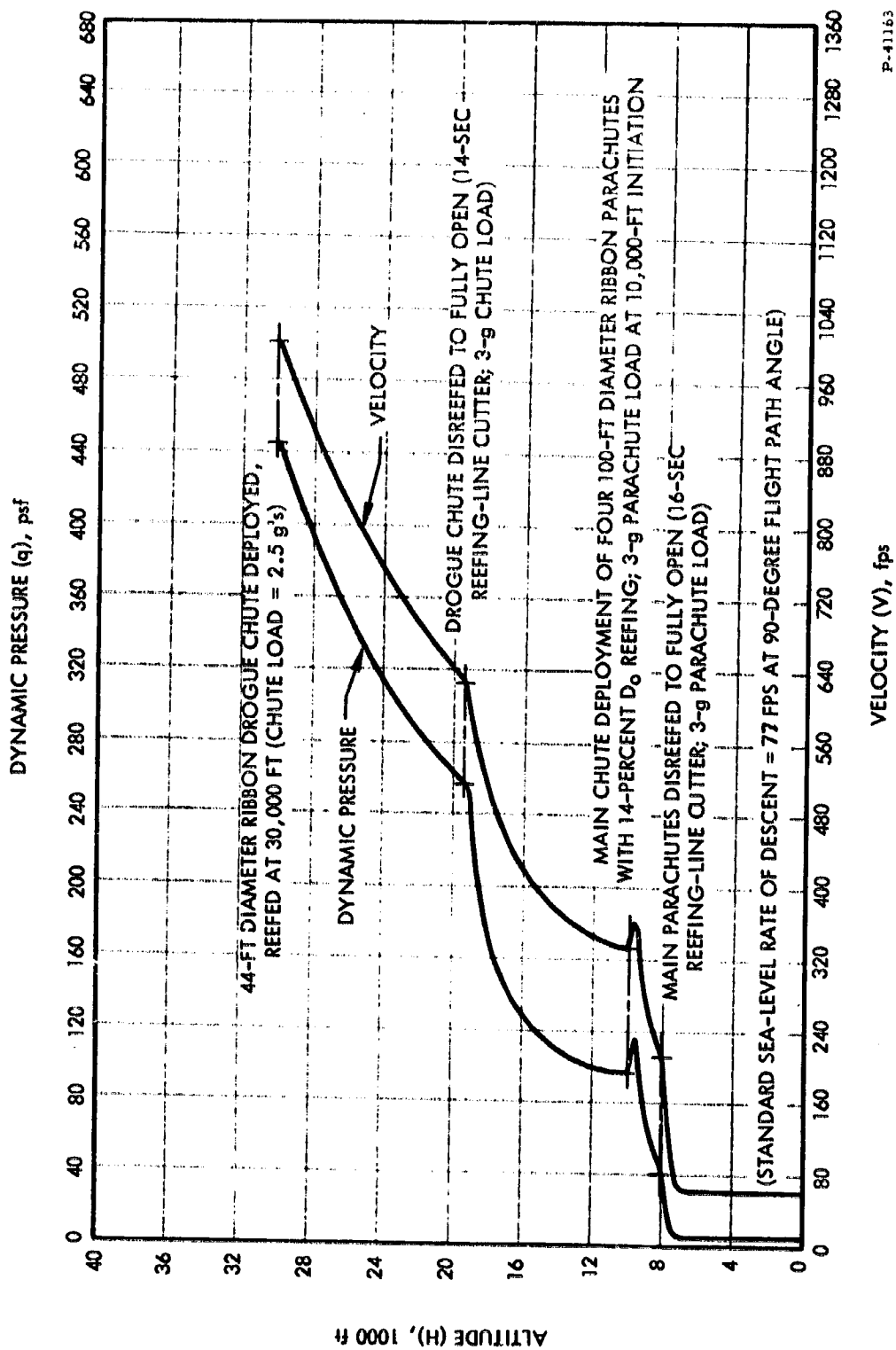


Figure 1-3. Parachute Sequence Controller

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Figure 1-4. Recovery System Deployment Profile - Velocity vs Dynamic Pressure

SRM submerges to a maximum depth of 60 ft. Water enters through the large nozzle to compress a large volume of air in the forward chamber. The SRM then comes to rest with the center of gravity well aft of the center of buoyancy and with the inclined nozzle down at about a 5- to 10-degree angle with the horizon (figure 1-5). The nozzle is submerged at this point and further entry of water is blocked.

As the LSD recovery vessel reaches the SRM, it offloads a small boat with two frogmen to strap on inflatable flotation rings to the fore and aft ends of the motor. These rings also facilitate flotation of the SRMs into the LSD and guard against damage to the SRM.

1.4.5 Parachute Container

The parachute container (figure 1-6) and nose cone replace the normal SRM nose cone. Weight of the parachute system is approximately 7,500 lb. Adequate space is available in the forward section for the complete parachute system; packaging presents no significant problem.

Preliminary design and stress analysis indicates that the maximum 3.5-g parachute impact load can be readily absorbed by the mounting structure and rings in the forward section of the SRM. Bending loads for canted SRM angles during parachute opening have been evaluated and present no major problem.

1.4.6 Segment and Closure Recovery Operations

Once the SRMs are loaded aboard the LSD, the motors are washed down with fresh water and dried using hot-air heaters (figure 1-7). The motors are offloaded at the Port Canaveral naval docks, disassembled at the center segment joint by removing the clevis pins, and trucked to the solid motor assembly area at Cape Kennedy. The motors are then fully disassembled, washed down with fresh water, and dried to remove all traces of salt water. The segments and closures are subjected to dimensional and NDT inspections. The MRB evaluates the inspection data and determines the acceptability of the segments and closures for refurbishment. Segments and closures which are acceptable are then adequately preserved and shipped to the UTC plant for refurbishment.

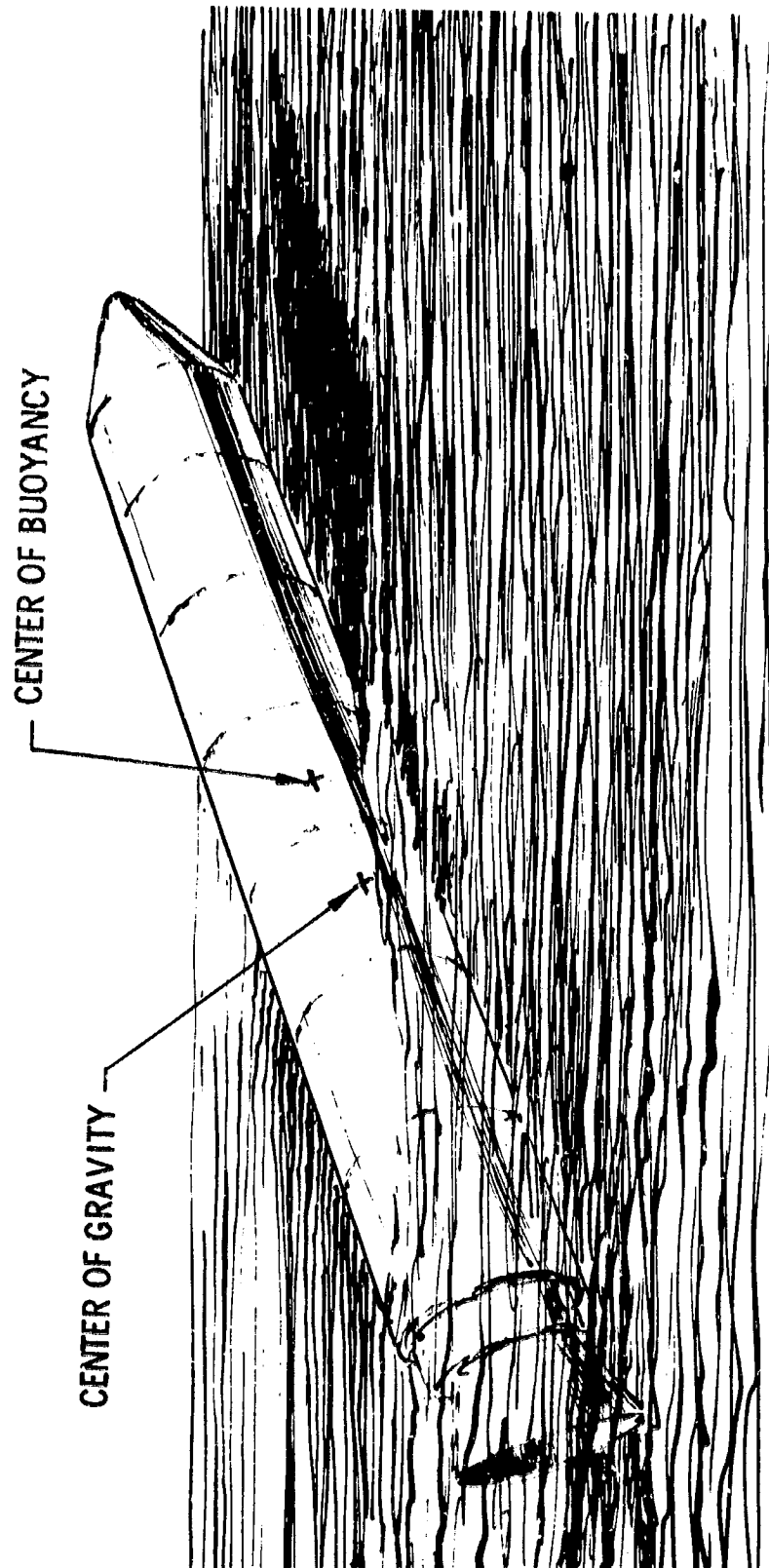


Figure 1-5. SRM Attitude During Flotation

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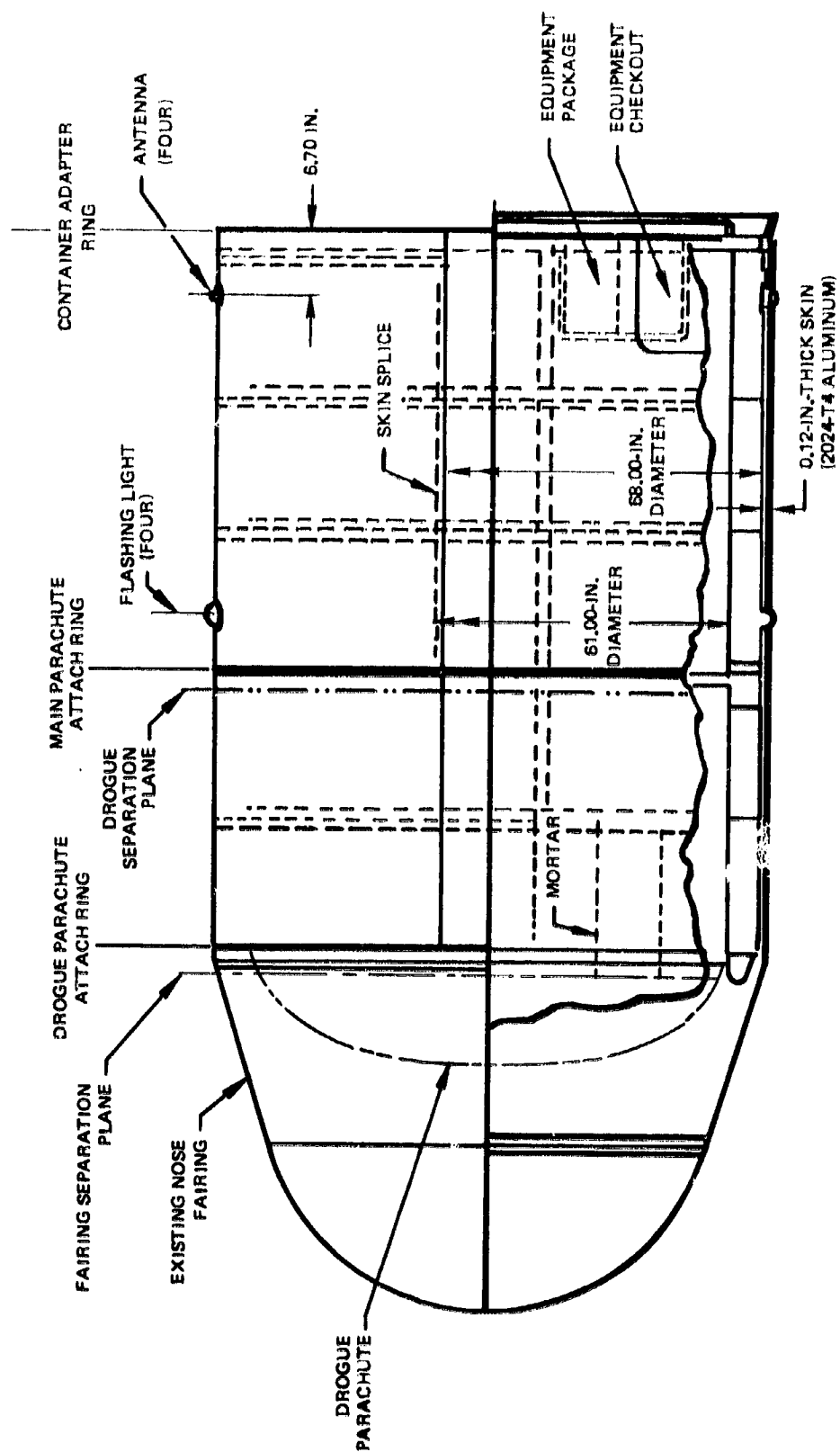


Figure 1-6. Parachute Container

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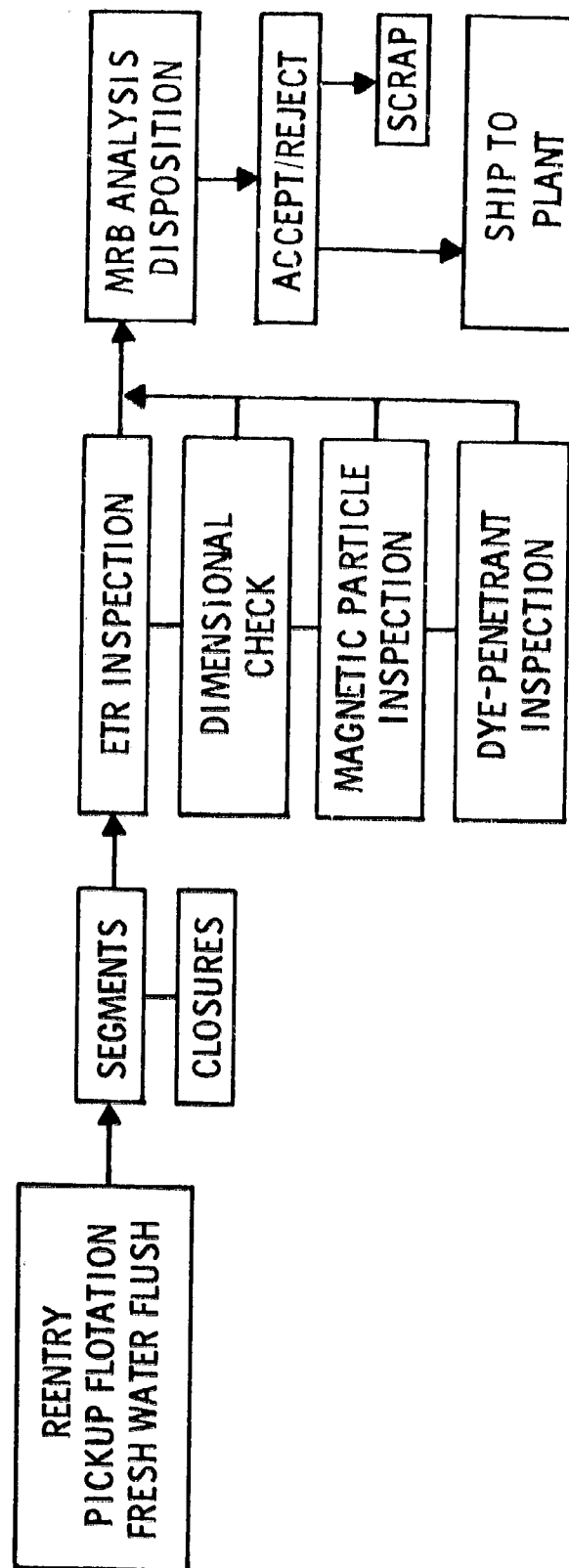


Figure 1-7. Segment and Closure Recovery Operations

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1.4.7 Segment and Closure Refurbishment

After recovery operations are completed at ETR, the SRMs are shipped to the refurbishment plant (figure 1-8). Activity for refurbishment consists of hardware cleanup, initial inspection for damage, and grit blast or rework as required. Segments and closures are then hydrotested to above MEOP to assume man-rating reliability. Final NDT consists of X-ray and magnetic particle inspections to locate any flaws or anomalies. The segments and closures are then reinsulated and enter the normal production-process cycle at UTC.

Forward and aft attach structure hardware is not hydrotested but does receive complete NDT, X-ray, and magnetic particle inspections followed by spray coating with a protective sealant.

1.4.8 Segment and Closure Rehydrotest

The success of multiple motor case reuse is dependent upon the ability of the D6aC steel to withstand low cycle fatigue without rupture and to resist the effects of salt water corrosion. Low cycle fatigue failure can result if sub-critical flaws in the metal grow with each cycle to critical size. However, a method of flaw evaluation has been developed to gain the full cyclic life of a pressure vessel.

This flaw evaluation method requires NDT inspection to ensure that there are no initial flaws of sufficient size to cause failure during the next flight operation. Also, to ensure recycle capability, the hydrotest pressure must be well below the case yield. From the table shown in figure 1-9, it can be seen that the proof test pressure is 14% below the case yield pressure, causing no permanent set or degradation in the material. Using these techniques between each operational cycle, the motor cases can withstand multiple reuse cycles with a high degree of reliability and confidence.

A UTC program was conducted in 1964 to determine the effects of unprotected D6aC steel immersed in salt water for up to 48 hr. It was found that for 48 hr, 0.002 in. of material removal was required. Under the present recovery time of 12 hr, the ratioed depth for removal of pits would allow the SRM hardware to be reused 24 times and still leave a positive margin of safety for man-rating.

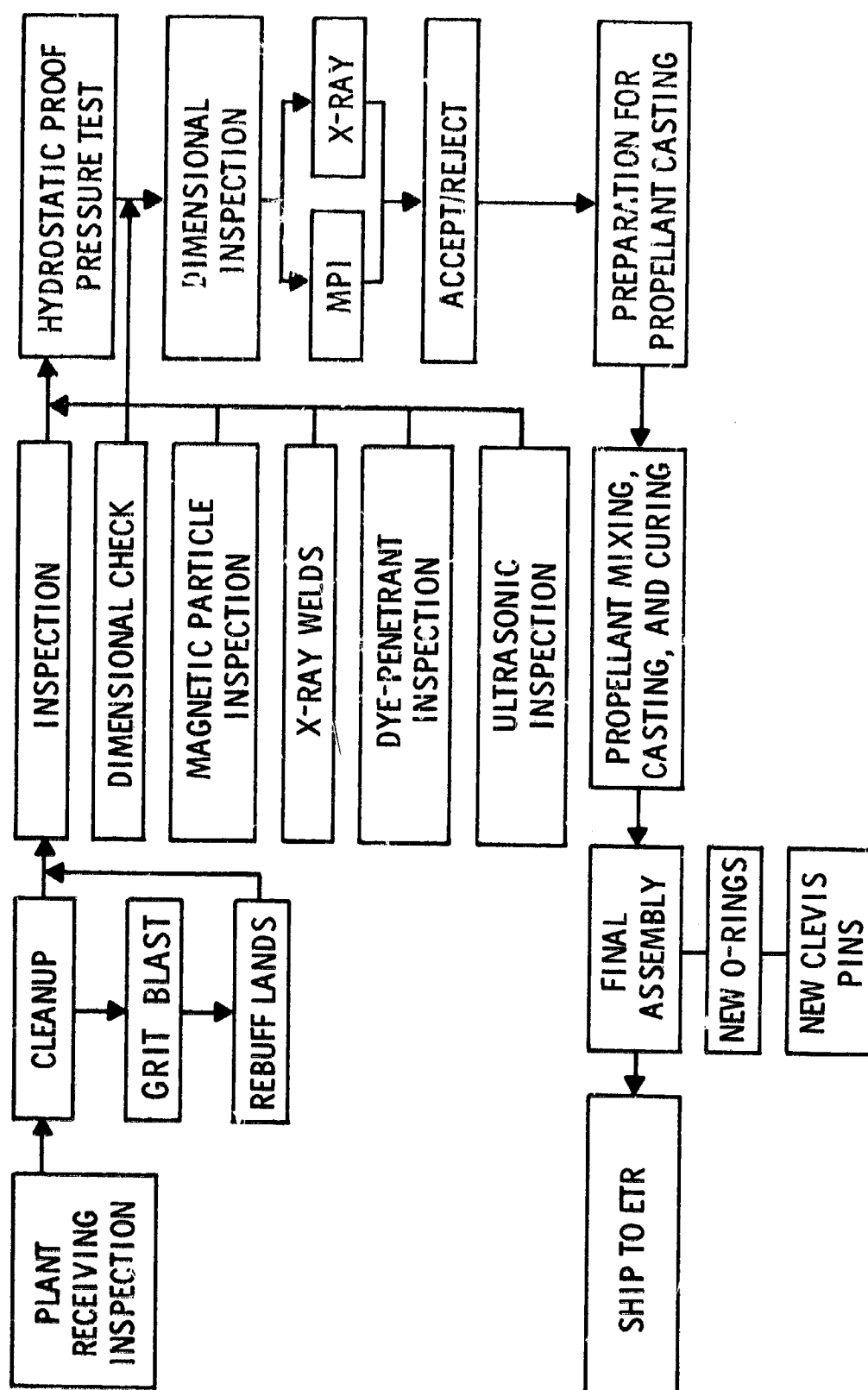


Figure 1-8. Segment and Closure Refurbishment

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CONDITION	PRESSURE PSI
MEOP	893
PROOF	947
CASE YIELD	1,110
DESIGN CASE BURST	1,236
ACTUAL TEST BURST	TBD

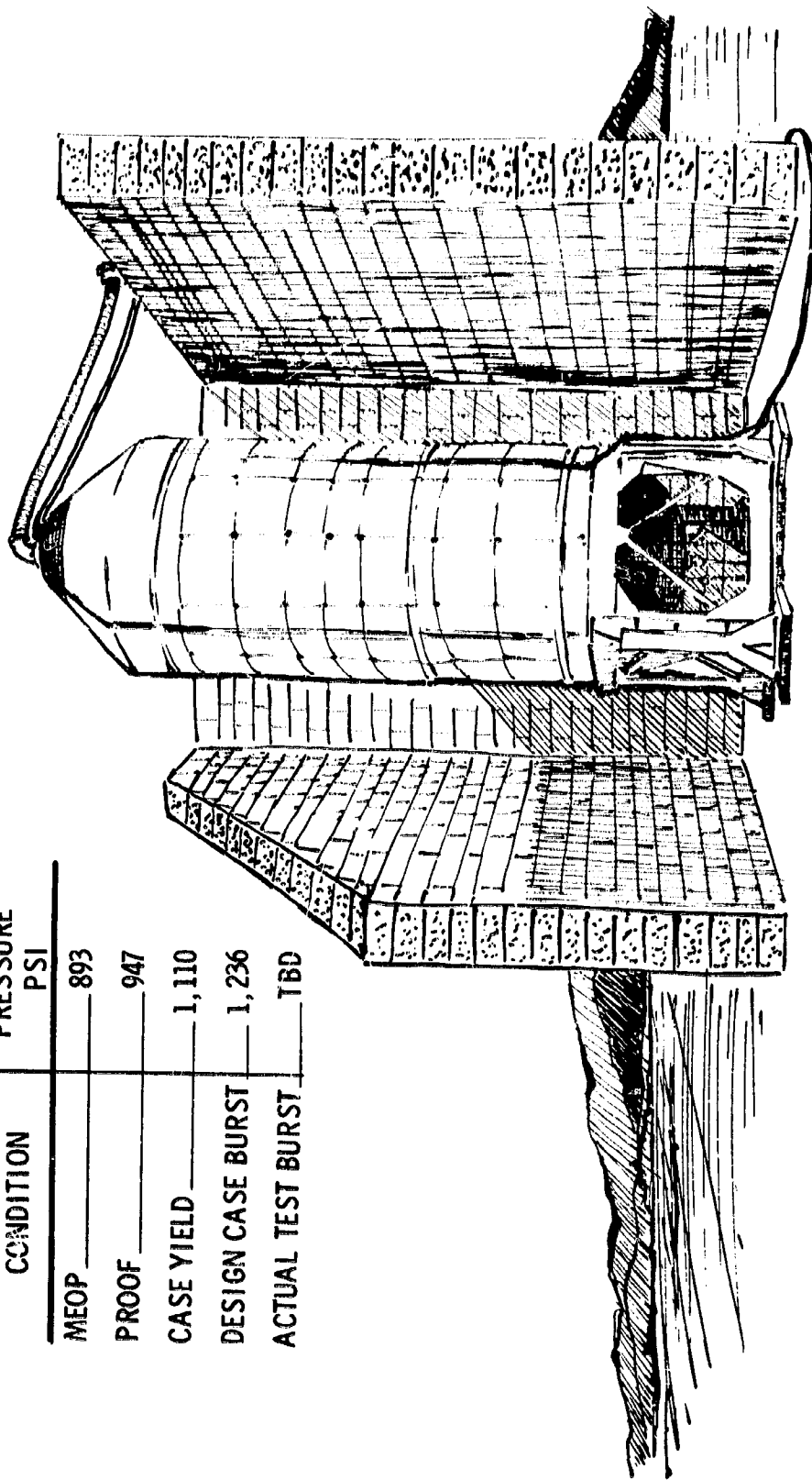


Figure 1-9. Segment Rehydrotest

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1.4.9 LSDs for Recovery

It is recommended that an LSD of the "Casa Grande" class be used for recovery of the SRMs (figure 1-10). These ships can readily load three 156-in.-diameter motors or six 120-in.-diameter motors. Two 50-ton cranes are mounted and movable on the sidedecks should they be needed. Cruise speed is 15 knots; a crew of 50 to 75 men is sufficient for short-term recovery action. Five of the ships are with the active U. S. Navy and six are "mothballed." It is estimated that a refurbished LSD can be obtained for about \$3,000,000.

The LSD will begin tracking radio signals from the SRMs as they separate at an altitude of 180,000 ft. The SRMs will impact within an 8-mile-diameter circle. After impact the LSD will drop off a small boat containing two frogmen alongside each SRM. Inflatable flotation rings will be installed fore and aft on each SRM to facilitate flotation and to protect the SRM from damage.

The LSD has an 18-ft draft which will allow each SRM to be floated aboard. Fresh water on board will be used to wash down the SRMs.

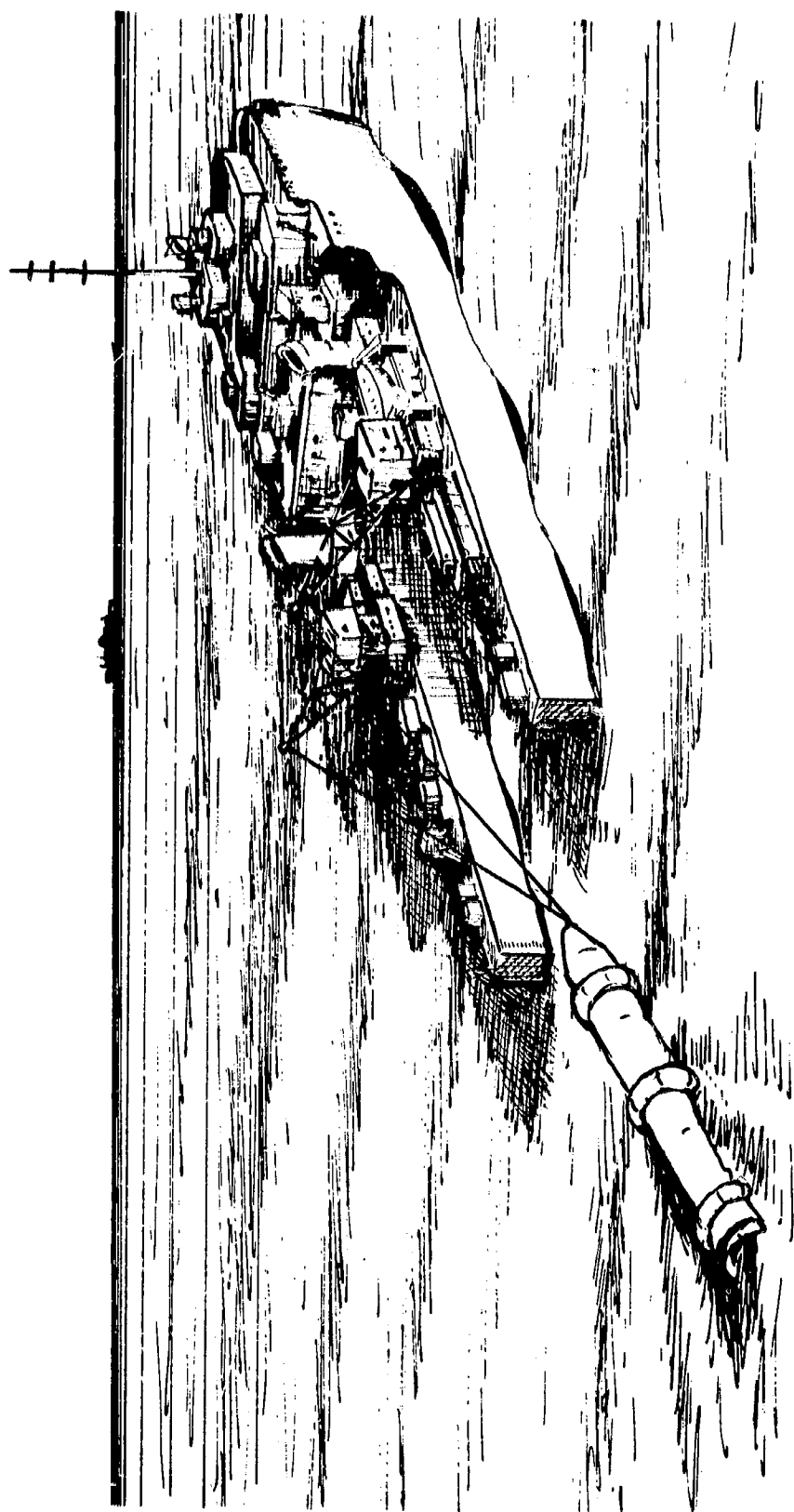


Figure 1-10. Landing Ship Dock

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2.0 COST ANALYSIS FOR RECOVERY OF THE SRM STAGE

2.1 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The cost savings, by mission model, which result from implementation of an SRM recovery program are presented in figure 2-1. This analysis shows major cost savings for each of the mission models and leads to the resulting conclusion that SRM recovery should be implemented in the Space Shuttle Program. This conclusion logically follows when the cost saving shown in figure 2-1 is compared with the nonrecurring cost of \$13,950,000 shown in table 2-1. The relatively small nonrecurring cost for development (i.e., \$13,950,000) will be amortized very early in the recovery program. The approximate cost saving resulting from recovery of SRMs then ranges from approximately 25% to 35% of the total SRM fabrication cost, depending upon mission model and quantity. Figures 2-2 and 2-3 clearly illustrate the cost incentive in booster hardware recovery.

Supporting information for these results is presented in the following pages and includes: considerations for parachute recovery system implementation; retrieval operations on the high seas; ETR acceptance and preparation of hardware for shipment to California; refurbishment of each SRM component; and delivery of all components to the UTC Development Center at Coyote, California, to reenter the normal process cycle for production of SRMs.

In concert with the latest emphasis on "prototype testing," UTC recommends immediate funding of \$110,000 to conduct a full-scale drop test of one seven-segment SRM. This test would be conducted using full-scale 120-in.-diameter SRM hardware presently available at UTC, and could be conducted within 3 months after go-ahead. Flight velocity and impact loads would be achieved by dropping the SRM from the San Rafael-Richmond Bay Bridge into San Francisco Bay. Price quotations have been received from the San Francisco Bay Bridge Authority confirming these costs and the feasibility of the test. Such a test would serve to confirm the results of this recovery study very early in the program.

Although this cost analysis is based on no redesign of SRM components to effect recovery, it should be noted that savings can be realized by redesign. In particular, if the electronic equipment is housed in shock-proof sealed containers, a savings increase of approximately 4% could be realized.

LAUNCH PROGRAM COST SAVINGS, MILLIONS OF DOLLARS

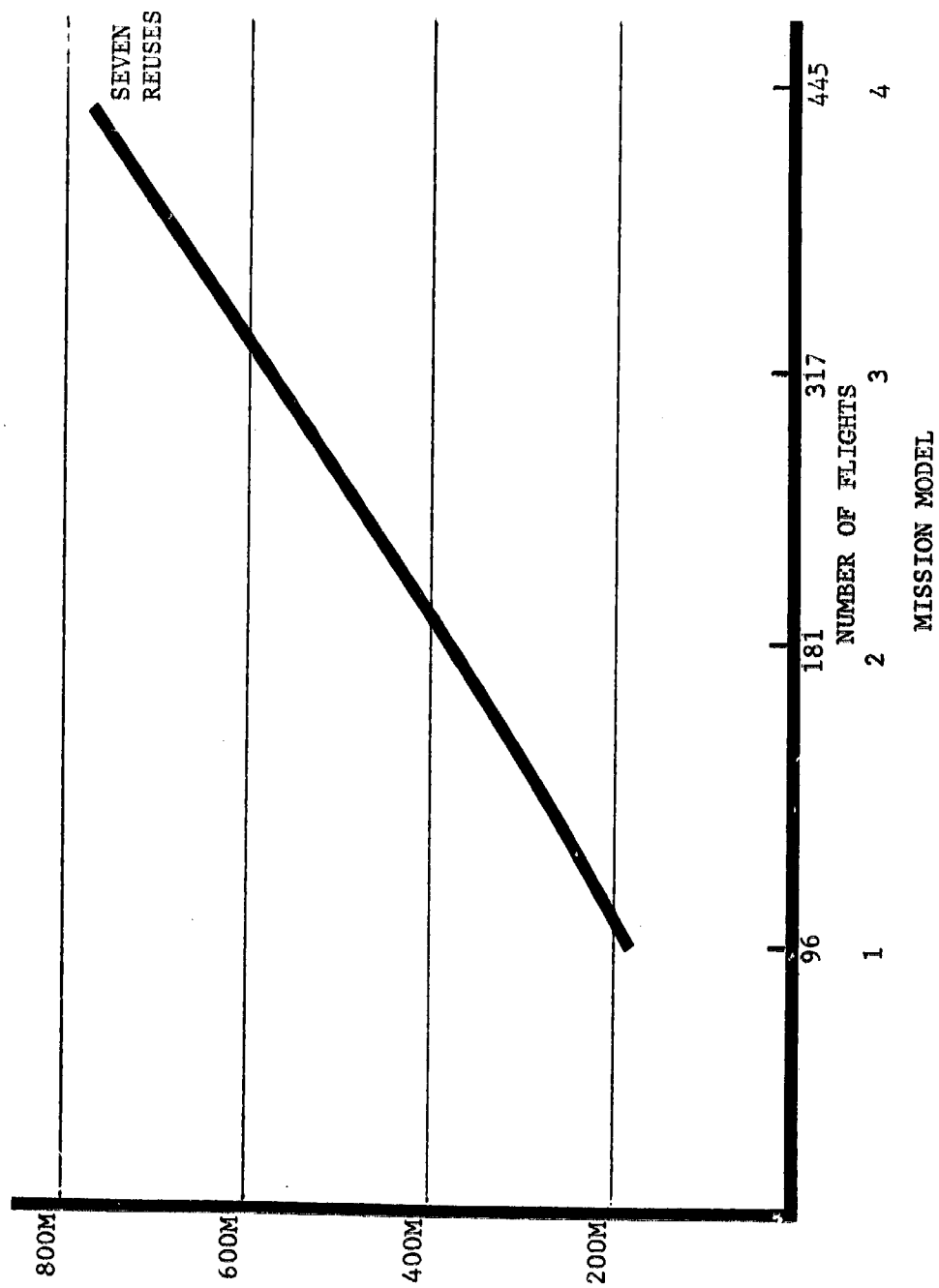


Figure 2-1. 156-In.-Diameter Parallel-Burn SRM
Program Cost Savings to Recover and Reuse

TABLE 2-1
RECOVERY DEVELOPMENT PROGRAM
(Sheet 1 of 2)

SRM Hardware Modifications to Incorporate Parachute System

<u>Modification</u>	<u>Cost</u>
Design, canister, and nose cone	\$ 90,000
Tooling for new canister	150,000
Tooling for new nose cone	100,000
Fabrication of four development units	200,000
Structural testing of nose cone and canister	200,000
Parachute development (modifications)	3,000,000
Modifications and bench testing of sequence controller and location aids	200,000
Linear-shaped charge design and qualification	130,000
Aeneroid sensor modifications	20,000
System integration	80,000
	<u>\$4,170,000</u>

Other Nonrecurring Costs for Recovery

<u>Item</u>	<u>Cost</u>
Crane and dock modifications at ETR	\$ 700,000
Handling - rings and equipment	200,000
LSD recovery modifications (fresh-water hoses, tiedowns, etc.)	220,000
Flotation collars (inflatable)	250,000
Nozzle plug for recovery	8,000
Special disassembly and cleanup tooling	100,000
Special refurbishment tooling	140,000
Tooling and spray equipment for protective coating	100,000
Miscellaneous	160,000
	<u>\$1,878,000</u>

TABLE 2-I

RECOVERY DEVELOPMENT PROGRAM
(Sheet 2 of 2)

Development Demonstration Program

<u>Item</u>	<u>Cost</u>
SRM impact test (water entry at 77 ft/sec) to verify component survivability	\$ 2,200,000
SRM water flotation tests to verify and evaluate the flotation attitude, stability, leakage characteristics, pickup requirements, and the effects of surface wave action	635,000
Evaluation of LSD recovery operations	120,000
Tests to verify that shock loads resulting from water entry at 77 ft/sec do not ignite the safe-and-arm pyrotechnics for the destruct and thrust termination system	14,000
Tests to evaluate the effect of salt water, salt-water spray, and corrosion on SRM components	42,000
Evaluation of protective coatings for SRM hardware	68,000
Air drop tests of the parachute recovery system using dummy payloads	3,600,000
Multiple hydrotesting of three segments and two closures to establish multiple reuse reliability	900,000
Motion picture coverage of the next Titan III launch to evaluate SRM postseparation dynamics	20,000
Nozzle impact load testing to verify action of the actuators and failure mode of the extension cone	190,000
Model testing, analytical studies, and specimen testing to direct, support, and supplement these demonstrations and to evaluate the specific recovery system	120,000
	<u>\$ 7,909,000</u>
Total development and nonrecurring cost	\$13,957,000

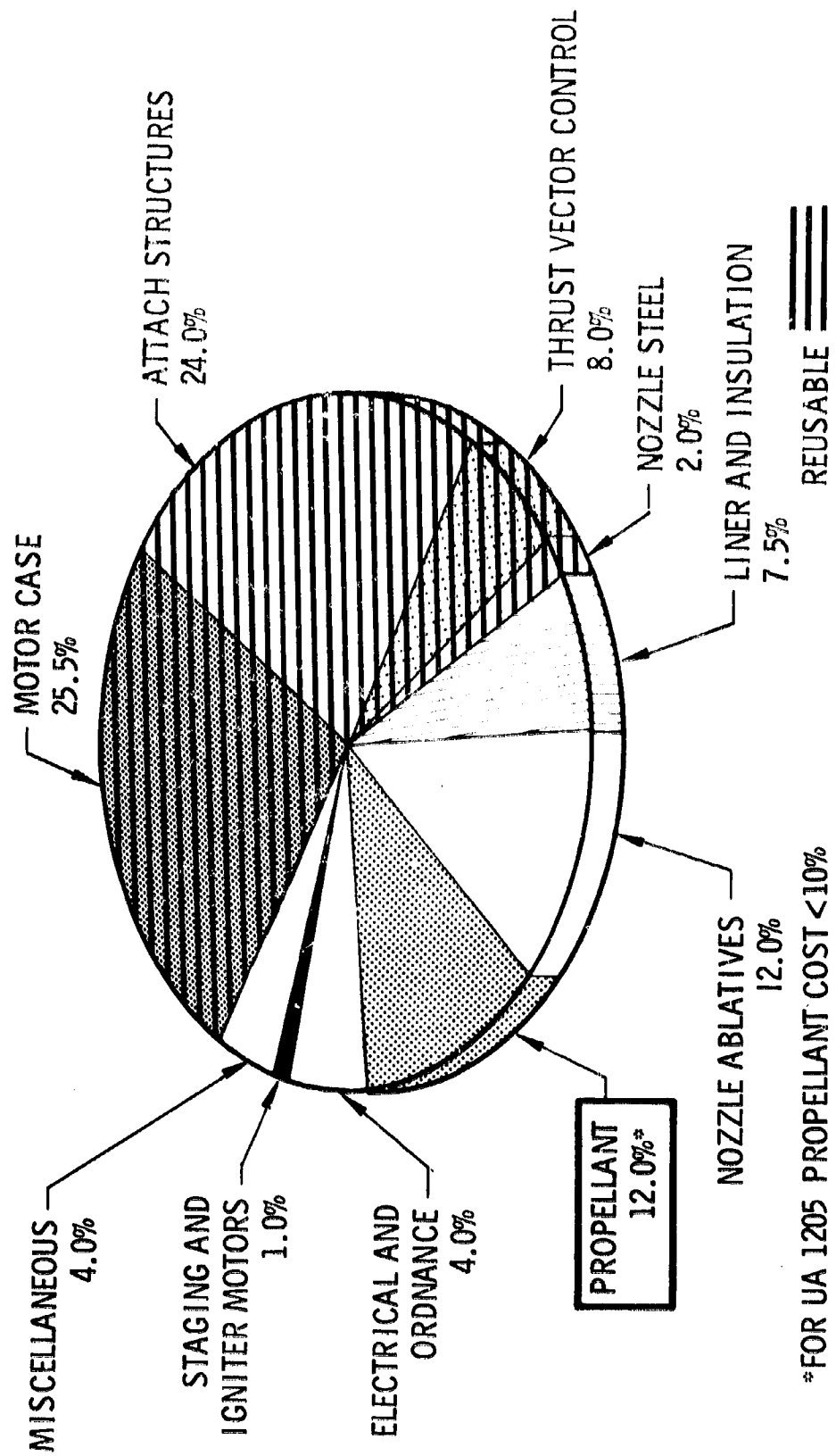


Figure 2-2. Typical SRM Hardware Cost Percentages

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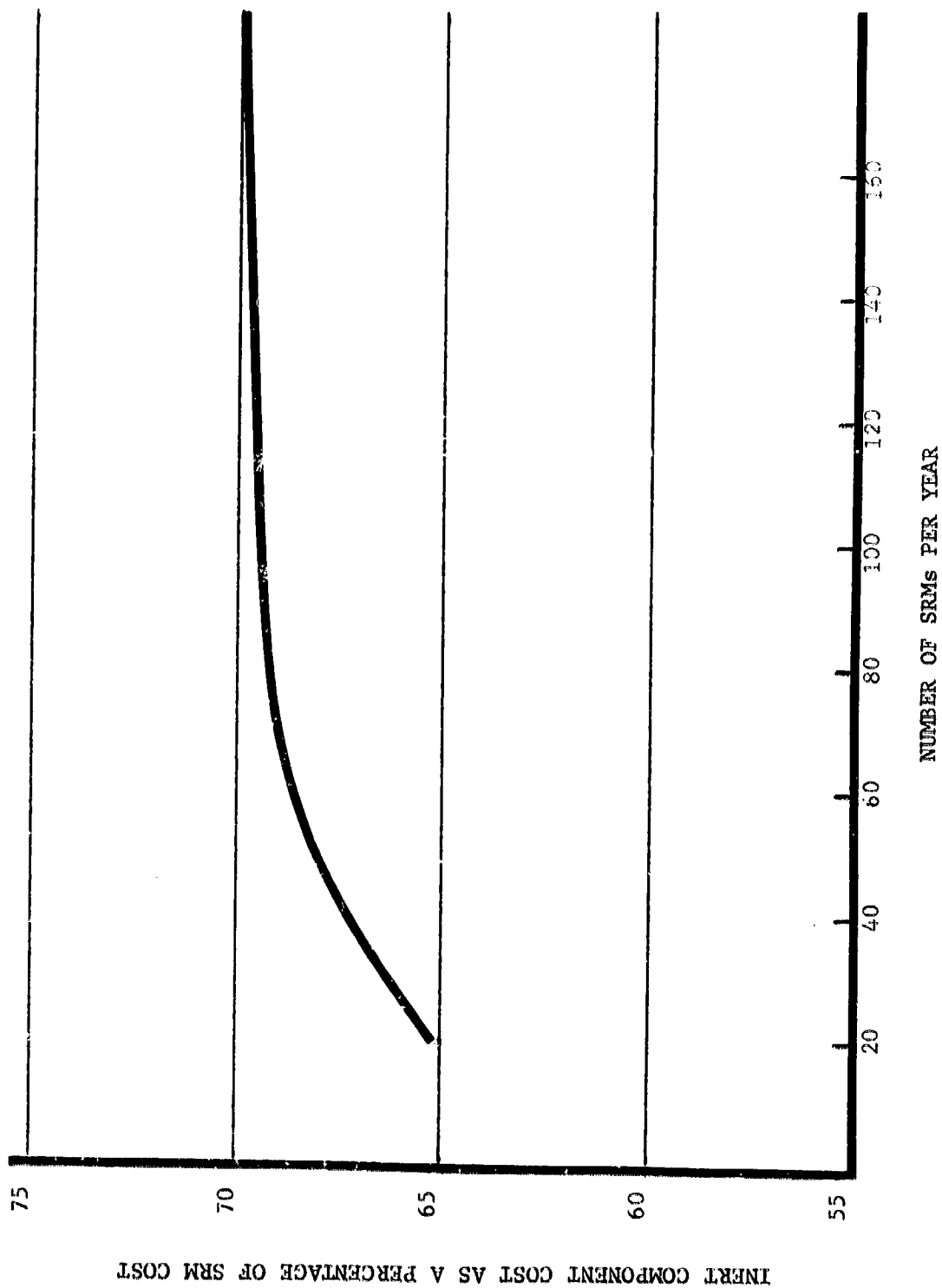


Figure 2-3. 156-In.-Diameter Parallel-Burn SRM
Inert Component Cost as a Percentage of SRM Cost

2.2 GROUND RULES AND ASSUMPTIONS

The costs presented herein are based on the following ground rules and assumptions:

- A. The number of flights are based on four space shuttle mission models as follows:

<u>Mission Model</u>	<u>Number of Flights</u>
1	445
2	317
3	118
4	96

- B. Two 156-in.-diameter SRMs are required per flight
- C. Costs are calculated based on the value of the dollar in 1970
- D. Launches are from ETR
- E. No new design of the SRM is required to implement recovery, except for the incorporation of a parachute system in the forward nose cone and the possible addition of one nozzle shock absorber
- F. Only major components of the SRM need to be recovered to effect a savings of 65% of the total inert cost per SRM
- G. Attrition rate for recovered SRM components ranges from 16% to 25%
- H. Major SRM components can be refurbished and reused seven times
- I. The variation in SRM component cost versus quantity ordered is approximately as shown in figure 2-4
- J. Recovered hardware is picked up by LSD and washed down with fresh water; cranes then offload the hardware onto trucks which deliver it to the UTC disassembly and inspection area at ETR
- K. Costs for shipment of hardware are included (no Government bill of lading assumed)

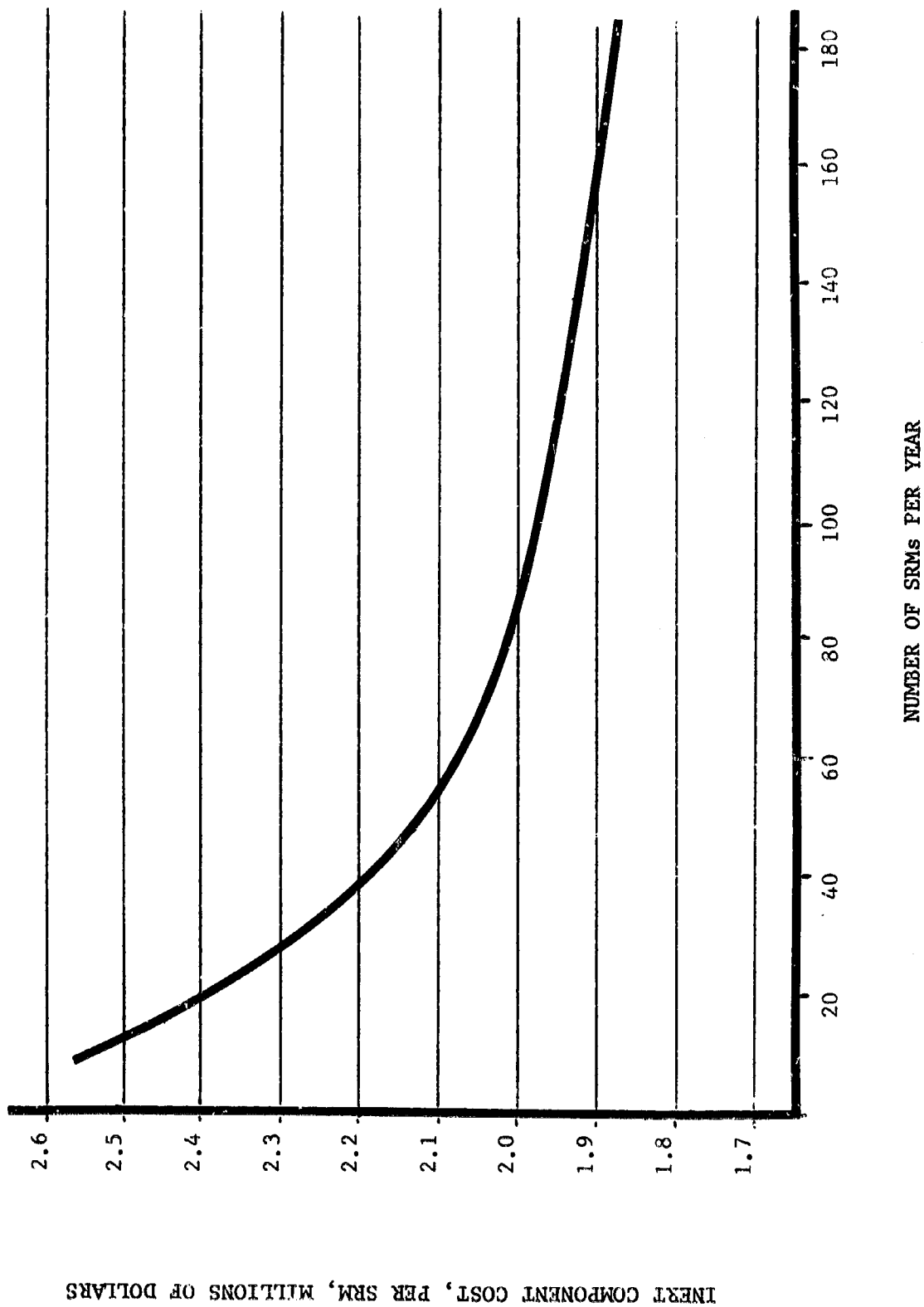


Figure 2-4. 156-In.-Diameter Parallel-Burn SRM
Inert Component Cost Reduction vs Quantity

- L. LSD recovery of four SRMs includes a 100-man crew operating the ship at \$20/man/hr for 32 hr, and special equipment and frogmen to be on station and enroute (recovery details are presented in table 2-II)
- M. Hardware items recovered and items not recovered are shown in figures 2-5 through 2-8 for each of the mission models
- N. Refurbishment of hardware will take place in California; shipment from ETR to California is \$24,500 per SRM (no Government bill of lading assumed).

TABLE 2-II

RECOVERY COST

<u>Recovery Operation</u>	<u>Time</u>	<u>Mission Model No. 4 (96 Flights)</u>	<u>Mission Model No. 1 (445 Flights)</u>
Parachute system	—	\$ 140,000	\$ 117,500
Nozzle shock absorber	—	13,000	11,050
Retrieval system			
LSD preparation or rental	—	10,000	10,000
100-man crew for LSD			
Dock to splashdown station, hr	6	6,000	4,920
At splashdown station, hr	20	20,000	16,400
Towing to dock, hr	6	6,000	4,920
Unloading and delivery to SMAB, man-hours	60	1,500	1,230
Cleanup and inspection for damage, man-hours	1,160	29,000	23,770
Packaging for shipment, man-hours	100	2,500	2,050
Total recovery (per SRM)		\$ 228,000	\$ 191,840

2.3 COST ELEMENTS

2.3.1 Cost of New SRM

The cost figures for new SRM hardware presented in figures 2-5 through 2-8 are based on recent vendor quotes for this study and on actual cost data

P-156" Diameter
3 Segment SRMs
445 Flights

Inert Items Reusable	All New Hardware	Hardware Recycled Seven Times + Attrition	Recovery and Refurbishment Seven Times
	Quantity	Quantity + Attrition	Recovery Refurbishment Shipping
Segments	2,670	334 + 16% = 387	
Forward Closure	890	111 + 16% = 129	
Aft Closure	890	111 + 16% = 129	
Aft Skirt	890	111 + 16% = 129	
Nozzle Steel	890	111 + 16% = 129	
Forward Thrust Skirt	890	111 + 16% = 129	
Nose Section	890	111 + 25% = 139	
TECHROLL Seal Hydraulics	890	111 + 25% = 139	
TECHROLL Seal Actuators	890	111 + 25% = 139	
Igniter Motor	890	111 + 16% = 129	
ISDS and Bridgewire Ordnance	890	111 + 25% = 139	
Raceways	890	111 + 25% = 139	
COST	\$1,279.0	\$240	\$149 \$104 \$19 \$272
Inert Items Not Reusable			
Heat Shield	890	No Reuse	Not Applicable
Nozzle Exit Cone	890	No Reuse	Not Applicable
Nozzle Ablatives	890	No Reuse	Not Applicable
Nose Cap	890	No Reuse	Not Applicable
Bridgewire and Ordnance	890	No Reuse	Not Applicable
Batteries and Cables	890	No Reuse	Not Applicable
Staging Motors	890	No Reuse	Not Applicable
Motor Insulation	890	No Reuse	Not Applicable
Other Miscellaneous Inerts	890	No Reuse	Not Applicable
COST	\$526	\$526	
Total Cost of Inerts	\$1,805	\$766	\$272

* Dollar Values Given in Millions

Total Cost Savings of 767 Million

Figure 2-5. Program Savings Based on Recovery of SRM Hardware

P-156" Diameter
3 Segment SRMs
317 Flights

Inert Items Reusable	All New Hardware Quantity	Hardware Recycled Seven Times + Attrition Quantity + Attrition	Recovery and Refurbishment Seven Times	
			Recovery	Refurbishment Shipping
Segments	1,902	238 + 16% = 276		
Forward Closure	634	80 + 16% = 93		
Aft Closure	634	80 + 16% = 93		
Aft Skirt	634	80 + 16% = 93		
Nozzle Steel	634	80 + 16% = 93		
Forward Thrust Skirt	634	80 + 16% = 93		
Nose Section	634	80 + 25% = 100		
TECHROLL Seal Hydraulics	634	80 + 25% = 100		
TECHROLL Seal Actuators	634	80 + 16% = 93		
Igniter Motor	634	80 + 25% = 100		
ISDS and Bridgewire Ordnance	634	80 + 25% = 100	\$115	- \$82
Raceways	634	80 + 25% = 100		\$13.7
COST	\$950	\$174		\$210.7
Inert Items Not Reusable				
Heat Shield	634	No Reuse		Not Applicable
Nozzle Exit Cone	634	No Reuse		Not Applicable
Nozzle Ablatives	634	No Reuse		Not Applicable
Nose Cap	634	No Reuse		Not Applicable
Bridgewire and Ordnance	634	No Reuse		Not Applicable
Batteries and Cables	634	No Reuse		Not Applicable
Staging Motors	634	No Reuse		Not Applicable
Motor Insulation	634	No Reuse		Not Applicable
Other Miscellaneous Inerts	634	No Reuse		Not Applicable
COST	\$392	\$392		
Total Cost of Inerts	\$1,342	\$566		\$210.7

* Dollar Values Given in Millions

Total Cost Savings of \$565 Million

Figure 2-6. Program Savings Based on Recovery of SRM Hardware

P-156" Diameter
3 Segment SRMs
181 Flights

Inert Items Reusable	All New Hardware		Hardware Recycled Seven Times + Attrition		Recovery and Refurbishment Seven Times	
	Quantity		Quantity + Attrition		Recovery Refurbishment	Shipping
Segments	1,086		136 + 16% = 1,575			
Forward Closure	362		44 + 16% = 51			
Aft Closure	362		44 + 16% = 51			
Aft Skirt	362		44 + 16% = 51			
Nozzle Steel	362		44 + 16% = 51			
Forward Thrust Skirt	362		44 + 16% = 51			
Nose Section	362		44 + 25% = 55			
TECHROLL Seal Hydraulics	362		44 + 25% = 55			
TECHROLL Seal Actuators	362		44 + 25% = 55			
Igniter Motor	362		44 + 16% = 51			
ISDS and Bridgewire Ordnance	362		44 + 25% = 55			
Raceways	362		44 + 25% = 55			
COST		\$584		\$95	\$66.5	\$47.4
						\$7.5
						\$121.4
Inert Items Not Reusable						
	Quantity					
Heat Shield	362		No Reuse		Not Applicable	
Nozzle Exit Cone	362		No Reuse		Not Applicable	
Nozzle Ablatives	362		No Reuse		Not Applicable	
Nose Cap	362		No Reuse		Not Applicable	
Bridgewire and Ordnance	362		No Reuse		Not Applicable	
Batteries and Cables	362		No Reuse		Not Applicable	
Staging Motors	362		No Reuse		Not Applicable	
Motor Insulation	362		No Reuse		Not Applicable	
Other Miscellaneous Inerts	362		No Reuse		Not Applicable	
COST		\$238		\$238		
Total Cost of Inerts		\$822		\$333		\$121.4

* Dollar Values Given in Millions

Total Cost Savings of \$368 Million

Figure 2-7. Program Savings Based on Recovery of SRM Hardware

P-156" Diameter
3 Segment SRMs
96 Flights

Inert Items Reusable	All New Hardware Quantity	Hardware Recycled Seven Times + Attrition Quantity + Attrition	Recovery and Refurbishment Seven Times	
			Recovery	Refurbishment Shipping
Segments	576	72 + 16% = 84		
Forward Closure	192	24 + 16% = 28		
Aft Closure	192	24 + 16% = 28		
Aft Skirt	192	24 + 16% = 28		
Nozzle Steel	192	24 + 16% = 28		
Forward Thrust Skirt	192	24 + 16% = 28		
Nose Section	192	24 + 25% = 30		
TECHROLL Seal Hydraulics	192	24 + 25% = 30		
TECHROLL Seal Actuators	192	24 + 16% = 28		
Igniter Motor	192	24 + 25% = 30		
ISDS and Bridgewire Ordnance	192	24 + 25% = 30		
Raceways	192	24 + 25% = 30		
COST	\$327	\$65.5	\$38.3	-\$27.4 \$7.1 \$69.8
Inert Items Not Reusable				
Heat Shield	192	No Reuse		Not Applicable
Nozzle Exit Cone	192	No Reuse		Not Applicable
Nozzle Ablatives	192	No Reuse		Not Applicable
Nose Cap	192	No Reuse		Not Applicable
Bridgewire and Ordnance	192	No Reuse		Not Applicable
Batteries and Cables	192	No Reuse		Not Applicable
Staging Motors	192	No Reuse		Not Applicable
Motor Insulation	192	No Reuse		Not Applicable
Other Miscellaneous Inerts	192	No Reuse		Not Applicable
COST	\$132	\$132		
Total Cost of Inerts	\$459	\$197.5		\$63.5

* Dollar Values Given in Millions

Total Cost Savings of \$192 Million

Figure 2-8. Program Savings Based on Recovery of SRM Hardware

accumulated during the past 9 years on the Titan III Program for 120-in.-diameter SRM hardware. Variations in unit prices with changes in quantity were determined by contacting the present vendors for Titan III 120-in.-diameter SRM hardware; these results are presented in figure 2-4.

2.3.2 Cost of Hardware Based on Recycling

When components are recycled seven times, a large cost saving results because of the reduced quantities ordered; however, the unit price of these components at the reduced quantities increases significantly. This is shown in figure 2-4. Also, an attrition rate must be added to the components ordered to account for recovery losses and quality control rejections. For the hardware in this costing, attrition rates vary from 16% to 25%, as shown in figures 2-5 through 2-8. These attrition rates cover all hardware losses during recovery and refurbishment operations, including quality control rejections.

2.3.3 Cost of Recovery and Refurbishment

A. Recovery

The recovery cost elements are shown in table 2-II and include a 100-man LSD crew operating for 20 hr in the splashdown area to recover four SRMs. Time to and from the splashdown area is also included at 6 to 9 hr each way. Frogmen are included in the LSD crew to perform in-water operations around the SRMs. The SRMs will be washed down with fresh water on the LSD and then delivered to the Naval docks at ETR for offloading by crane onto flat-bed trucks. The trucks will then deliver the hardware to the UTC disassembly and inspection area at ETR. The washdown and disassembly will be followed by application of protective coatings and shipment to California. It is estimated that the cost of an LSD of the "Casa Grande" class will be approximately \$3,000,000, should it be desirable to purchase one outright. At this time, five of these ships are in the active U.S. Navy and six are "mothballed". The rental cost, included in the recovery expense, is sufficient to purchase one LSD.

B. Refurbishment

After the recovery operation is completed, the SRM components are shipped to California for refurbishment. The refurbishment operation for each

component is shown in table 2-III. After cleaning and inspection, the case segments and closures are hydrotested and magnetic particle inspected. The hardware is then reinsulated and enters the normal production cycle for propellant loading, assembly, and buyoff at the UTC Development Center, Coyote, California.

C. Shipment

Shipment cost for one SRM from MTR to California is \$24,500. This cost is included for all recycled hardware. Government bill of lading is not considered for purposes of this study.

2.4 OTHER CONSIDERATIONS

Although this study is based primarily on the reuse and recycle of hardware seven times, it should be noted that it is completely feasible to recycle hardware many more times. Figure 2-9 shows the additional cost saving with up to 100 reuses of hardware. These costs must, however, include much higher attrition rates as the reuse of hardware increases; e.g., for the 100-reuse curve, attrition rates up to 42% for some components are included.

TABLE 2-III
REFURBISHMENT COST

Refurbishment Operation	Man-hours	Cost/SRM	
		Mission Model No. 4 (96 Flights)	Launch Model No. 1 (445 Flights)
Shipment from ETR to California	—	\$ 24,400	\$ 24,400
Refurbishment of Segments and Closures			
Receiving inspection	85	2,120	1,740
Remove insulation	936	19,900	16,300
Sandblast	65	1,590	1,430
Full MPI	65	1,590	1,430
Hydrotest	255	6,360	5,230
Full MPI	65	1,590	1,230
Full quality control acceptance	128	3,190	2,610
Paint and protect surfaces	105	2,660	2,180
Delivery for insulation	—	220	170
Material	—	6,800	5,570
Handling	—	2,220	1,740
Liaison support	238	5,950	4,930
Refurbishment of nose section forward and aft skirts			
Receiving inspection	68	1,700	1,394
Remove protective coating	170	4,250	3,485
Clean and passivate	340	8,500	6,970
Full MPI	170	4,250	3,485
Dimensional inspection	170	4,250	3,485
Paint and apply protective coat- ing and external insulation	850	21,250	17,340
Full quality control acceptance	170	4,250	3,485
Materials	—	23,800	19,550
Handling	—	2,040	1,700
Liaison support	272	6,800	5,610
Refurbishment of other motor components (igniters, hydraulic and actuator systems, parachute canister, nozzle steel, and ISDS)			
Inspection, clean, passivate, MPI, paint, and quality control acceptance	850	21,250	17,340
Materials and handling	—	3,400	2,720
Liaison support	93	2,890	2,380
Total refurbishment (per SRM)		<u>\$187,220</u>	<u>\$157,904</u>

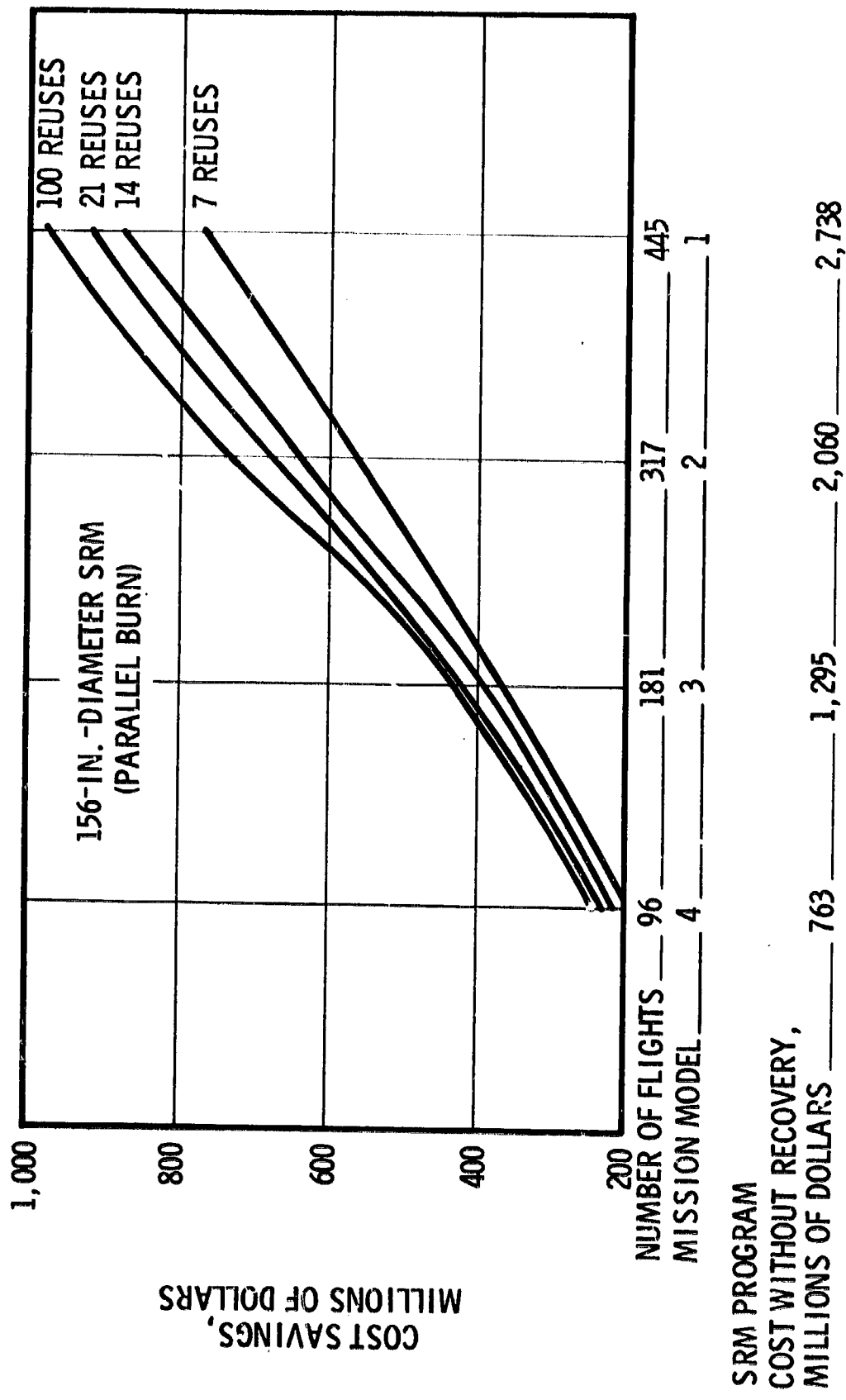


Figure 2-9. Program Savings Based on Recovery and Reuse

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